Seventy years of research in mineralogy and crystallography in the Department of Mineralogy, British Museum (Natural History), under the Keepership of Story-Maskelyne, Fletcher, and Prior: 1857–1927

W. Campbell Smith

Department of Mineralogy, British Museum (Natural History), Cromwell Road, London SW7 5BD

Research in mineralogy and crystallography based on the great collections in the Department of Mineralogy began only after the appointment of Professor Nevil Story-Maskelyne as Keeper of Minerals in 1857.

N. S. Maskelyne, as he was generally known, had taken his degree in mathematics at Oxford in 1845; and he had also studied chemistry and conducted further study for a time in Faraday's laboratory at the Royal Institution. Since 1850 he had been acting as deputy to William Buckland whose health was beginning to fail and he succeeded him as Reader in Mineralogy at Oxford after Buckland's death in 1856. This appointment fortunately did not debar him from accepting the post of Keeper of Minerals at the British Musem offered him in the following year. He occupied both positions with distinction until 1880 when he resigned his museum appointment, his father having died the previous year leaving him heavy responsibilities on the family estate in Wiltshire (Spencer, 1911*b*).

Maskelyne's predecessor as Keeper of Minerals was Charles Konig, who had become Keeper of Minerals (including secondary fossils) in 1837, when the old Natural History Department of which he had had charge since 1813 was divided into three: Botany, Zoology, and Mineralogy. Konig had always devoted much of his time to the care of the mineral collections; however, he had neither the opportunity nor the facilities for any crystallographical or chemical research beyond tests needed for identification. In the galleries and rooms occupied by the mineral collections facilities for laboratory work seem to have been minimal and apparatus almost non-existent. Maskelyne overcame some of these difficulties and he and his few assistants, never more than one at a time, achieved much in descriptive mineralogy and crystallography. No artificial light was allowed in the old buildings, except in a locked lantern brought on request by an attendant, and Konig had complained that he could not use his reflective goniometer either in his room or in the gallery. Maskelyne installed a heliostat so, at least when the sun shone, a steady light source was available (Campbell Smith, 1969).

At first the only help Maskelyne had was one 'Third Class Attendant', Thomas Davies, the son of William Davies who was an Attendant in the Department of Geology. Thomas Davies was twenty when appointed to the Museum staff, having already spent four years at sea. He knew little about scientific mineralogy, but he developed a flair for remembering and recognizing the important characters of specimens and under Maskelyne's tuition became a very competent curator (Fletcher, 1893*c*).

It is hard to over-estimate Maskelyne's influence, for it pervaded the whole of the seventy years under review, and this is scarcely surprising since he at the British Museum and Oxford, and W. H. Miller at Cambridge, together kept mineralogy and crystallography alive in England in the third quarter of the nineteenth century. The recruitment, in later years, of Fletcher, Lewis, Miers, Prior, Spencer, Herbert Smith, Campbell Smith, and Mountain—all Oxford or Cambridge men—was one direct consequence.

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Maskelyne's decision to adopt Gustav Rose's system of classification (1852) for the arrangement of the mineral collection—a task which must have occupied the greater part of his early years at the Museum—together with his interests in optical and morphological crystallography, and chemical analysis, determined the direction of research, for it revealed many gaps in the collections and deficiencies in the descriptions of mineral species in the literature. It was not until 1927, when Bannister was appointed to develop in the Department the application of X-ray diffraction techniques to minerals, that there was a significant addition to the methods of investigation initiated by the perceptive Maskelyne. By 1863 he had completed the rearrangement and was able to issue a 'Catalogue of Minerals with references to the table cases . . . in the British Museum'; a new edition was published in the following year. Later editions were entitled 'Index to the Collection of Minerals . . .' and 'A Guide to the Collection of Minerals, British Museum' had appeared in 1862.

In 1862 Maskelyne had invited Viktor von Lang of Vienna to join the Museum staff. Von Lang, then a young man of 24, was a Privat-Dozent in physical crystallography in Vienna. After two years at the British Museum he returned to Vienna and became Professor of Physics there in 1865. He published his *Lehrbuch der Krystallographie* in 1866 and, one supposes, exchanged ideas freely with Maskelyne who also had *Treatise on Crystallography* in hand at the same time, although regrettably, he did not publish his (Maskelyne, 1895) until thirty years later (Spencer, 1921*b*). Maskelyne and von Lang jointly published several notes on minerals from Cornwall and elsewhere and he also described a new mineral, langite, named for von Lang (Maskelyne, 1864*a*). Von Lang himself contributed notes on the crystalline form of lanthanite; on new forms in mesotype (natrolite) measured on crystals labelled brevicite; on malachite, describing crystal forms and optical properties; on some artificial crystals of gold, sent by Dr Percy; and on some combinations of eudialyte (Maskelyne & von Lang, 1863*a*). In the following year, 1864, his Mineralogical Notes dealt with gadolinite; and with gismondine and herschelite, a variety of chabazite in which he demonstrated the pseudo-hexagonal twinning (Maskelyne & von Lang, 1864).

These 'Notes' were mainly descriptions of the crystal forms of the minerals discussed, with records of the measurements of angles. In some cases the only crystals available were very small and in his first paper on connellite Maskelyne described how they overcame the difficulty of measuring them; the same specimen of connellite, from St Day United Mines, was the subject of a subsequent X-ray study by Bannister *et al.* (1950). Noting that some crystals were very small (less than about 2.5 mm long) and richly facetted, he wrote: 'it would be almost impossible to obtain measurements of any value by the ordinary reflecting goniometer. But by means of a small plano-convex lens in front of a small telescope with magnifying power about nine times attached to the goniometer, and which converts that telescope into a sort of microscope of low power, it is not difficult to obtain measurements of considerable exactitude' (Maskelyne & von Lang, 1863*a*). The idea of using an auxiliary lens in front of the telescope is probably attributable to Mitscherlich (1843), and von Lang, as a result of his work at the British Museum, devised an improved goniometer which he described in 1876.

After von Lang's return to Vienna there was an interval of three years during which Maskelyne worked alone and published several papers on rare minerals from Cornwall, describing two of these, lyellite and waringtonite, as new minerals (Maskelyne 1864*b*). They are now known to be synonyms of langite and brochantite. In 1877 he published three notes on the crystallography and optical characters of the new mineral ludlamite (Maskelyne 1877*a,b,c*), described by Field (1877) and in the following year he announced the discovery of another new Cornish mineral, liskeardite (Maskelyne, 1878).

By 1863 and 1864 Maskelyne had begun publishing the results of his work on the meteorite collection and he contributed in addition to his Notes with von Lang a short paper on 'aerolites' (Maskelyne, 1863), and one on 'meteoritic stones' (Maskelyne, 1872*c*). He continued this work on meteorites using thin-sections and a Powell and Lealand microscope purchased in 1863 to which he had had fitted a polarizer and analyzer and a rotating stage, and in 1870 and 1871 he published four important papers on the mineral constituents of meteorites, which he had read before the Royal Society (Maskelyne, 1870*b,c*; 1871*a,b*). His last paper on meteorites before he

left the Museum was a brief note on the Rowton siderite which had been seen to fall on 20 April 1876; it remains the only iron meteor seen to fall in Great Britain (Maskelyne, 1876).

At about this time Maskelyne turned his attention to the study and identification of precious stones. He prepared the 'Report on Jewelry and Precious Stones' for the Paris Universal Exhibition (Maskelyne, 1868) and later catalogued the Marlborough gems at Blenheim Palace; this was privately printed (Maskelyne, 1870*a*).

In 1867 a chemical laboratory was fitted up in a nearby house, 46 Great Russell Street, and Walter Flight was appointed as an additional Assistant. This tradition of chemical analysis continued in direct succession to Prior, Mountain (briefly), Hey and on to the present day. Flight was a highly qualified chemist, having studied in the Universities of Halle and Heidelberg and worked for a time in Professor A. W. Hofmann's laboratory in Berlin.

Maskelyne and Flight together published a series of fifteen Mineralogical Notes in the *Journal of the Chemical Society* (1871, 1872, 1874) dealing with some sixteen minerals. Several of the specimens were submitted by R. Talling, the mineral dealer of Lostwithiel: some were known to be from Cornwall and probably all of them were, but Talling did not always 'reveal' his localities. The specimens were of vivianite, cronstedtite, 'francolite', a mineral described as prasine (a synonym for pseudomalachite), and a specimen believed to be the woodwardite of Church but shown by Maskelyne and Flight to consist of langite with 'one or more hydrated aluminium silicates'. The 'francolite' was shown to be a fluor-apatite but not the same as the francolite from Wheal Franco, although Dana quotes Flight's analysis as being that of francolite (Dana, 1892, pp. 765–6). Another analysed specimen from Cornwall is uranite from near Redruth, but the analysis shows 2.5% of bismuth oxide and only about 4% CuO (Maskelyne & Flight, 1872).

Andrewsite, another Cornish mineral, was described in the last of this series of Mineralogical Notes, and so also was chalcosiderite to which andrewsite is very close (Maskelyne, 1872*b*, 1875*a*). Maskelyne gave measurements and a drawing of a crystal of chalcosiderite, both reproduced by Dana (1892, p. 854) quoting analyses from an earlier paper (Maskelyne & Flight, 1871).

Other specimens reported on are: pisolitic iron ore from North Wales and Anglesey; Iona stone, 'miscalled jade'; caledonite from Leadhills, Wanlockhead, and lanarkite; opal from Waddela Plain, Abyssinia, collected by Mr Masham on Napier's expedition in 1868; 'isopyre' from South Africa; and percylite probably from the same locality; and vanadinite. On a small crystal of percylite Maskelyne succeeded in obtaining a measurement of three planes in a zone giving angles corresponding with those of the rhombic dodecahedron (Maskelyne & Flight, 1872).

One of the earliest of these notes (no. 7) (Maskelyne & Flight, 1871), gives an analysis of a mineral, 'meerschaluminite', described by Major W. A. Ross (1869), which is shown to be near pholerite, a variety of kaolinite. Flight's last mineralogical paper was on two new minerals, evigtokite and liskeardite (Flight, 1883); he died in 1885 at the early age of forty-four.

Reading through these notes of over a century ago, it may seem that they are now of little importance. However, most of Flight's analyses were quoted by Dana in the early editions of his *System of Mineralogy* and some of them were still the only ones available when he published his sixth edition in 1892.

The next addition to Maskelyne's staff was one of his own Oxford pupils, William James Lewis. Lewis had worked in the Department as an 'outside worker' in 1872 and was appointed an Assistant in 1875; but he had to resign in 1877 because of lung trouble. By way of effecting an improvement in his condition he joined an expedition to Spitsbergen. On his return he went to Cambridge to act as deputy to Professor W. H. Miller, whose health was failing; he succeed Miller as Professor in 1881 and occupied the chair for 45 years until his death in 1926.

His published work during his period at the Museum consisted of papers on glaucodote, sphene, gold, and barium nitrate which were published in the *Philosophical Magazine* and reprinted in the *Proceedings of the Crystallological Society* of which Lewis was the first, and last, Secretary (Lewis, 1877*a*,*b*). A notebook kept by Lewis when an 'outside worker', dated 1872, records measurements on glaucodote, and on pyrite and cobalt glance (cobaltite). His observation books from May 1875 to 1876 record measurements on gold, copper, sulphur, skutterudite,

mispickel, (arsenopyrite), argentite, redruthite (chalcosine), blende, greenockite, galena, and calcite.

He was an enthusiastic measurer of crystals and to work with him on a difficult crystal was an absorbing occupation. He worked with a student's Wollaston vertical circle goniometer in the old mineral gallery in the Free School Lane buildings and used as his light source the signal in the window opposite illuminated by a tilting mirror on the window sill outside. I never saw him use such a modern piece of apparatus as a horizontal circle goniometer. Spencer, in his obituary notice of Lewis, said of him 'To his credit he made no great burden for the bibliographer. In the preparation of his excellent text book on geometrical crystallography published in 1899, he devoted much time and infinite pains' (Spencer, 1927*a*).

Lazarus Fletcher, who was to be Maskelyne's successor as Keeper of Minerals and ultimately Director of the Natural History Museum, was appointed an Assistant in the Mineral Department in 1878. He was a mathematician already with a distinguished career at Oxford, a Fellow of University College, a Demonstrator in the Clarendon Laboratory under Professor R. B. Clifton, and Millard Lecturer in Physics at Trinity College. His life and work have been admirably described by Sir Henry Miers (1921) in a biographical notice. Miers has told how through Fletcher's chance scanning of the pages of Groth's *Physikalische Krystallographie* he became interested in crystallography and was soon brought to the notice of Professor Story-Maskelyne. There was a vacancy in the Department of Mineralogy in the British Museum caused by Lewis' early retirement and Maskelyne suggested that Fletcher should be a candidate. He was appointed an Assistant in 1878, and succeeded Maskelyne as Keeper on the latter's retirement in June 1880.

Fletcher's first task was to supervise the removal of the collections from Bloomsbury to the new Natural History Museum in South Kensington. This commenced in July 1880 and lasted until the new Museum was opened to the public in April 1881. During the move Fletcher had the assistance of H. M. Platnauer and Thomas Davies. In the first few years after the move of the collections Fletcher can have had little time for any crystallographic or mineralogical research. He had published an 'Index to the Collection of Minerals', and a 'Guide to the Collection of Meteorites' in 1881, and had completed his guide and 'Introduction to the Study of Minerals' in 1884. However, while still at Bloomsbury he had begun work on the 'Crystallographic Catalogue' which Maskelyne, no doubt influenced by the purchase in 1860 of the Allan-Greg collection, started in 1875 as a 'scientific catalogue of the whole collection, with crystallographic descriptions and chemical analyses of those specimens the composition of which it is desirable more accurately to determine'—as he himself described it in his annual return for that year (Campbell Smith, 1952). All new recruits to the Department (until about 1950) were assigned work in connection with this catalogue and it set the pattern of, and provided the material for, much mineralogical research.

The results of Fletcher's work for this catalogue, beginning with the native elements and simple sulphides, resulted in a series of Crystallographic Notes published in the *Philosophical Magazine* and reprinted as part of the *Proceedings of the Crystallological Society*. The first of these notes described crystals of copper, silver, gold, bismuth, sulphur, nagyagite, and realgar (Fletcher, 1880*b*) followed, after the move, by a description of a twin of zircon (Fletcher, 1881), a note on crystals of skutterudite (Fletcher, 1882*a*), and an important paper on copper pyrite twins (Fletcher, 1882*b*). In addition to this work on minerals Fletcher wrote an important paper on 'The dilatation of crystals on change of temperature' (Fletcher, 1880*a*), published before his first crystallographic notes. Miers (1921) has given an account of the interest aroused by this paper and of how Fletcher set about a fresh study of the whole problem, work which was interrupted by illness but nevertheless finished and, with Miers' help, published (Fletcher, 1883).

Later, Fletcher returned to a kindred subject on which he could use his mathematical ability and his training in physics. This produced what Miers described as 'the highest achievement of his scientific life', the remarkable memoir on 'The optical indicatrix and the transmission of light through crystals' (Fletcher 1891), published also in book form in 1892*a*, and in German translation in 1893*f*.

In 1886 Fletcher produced an 'Introduction to the study of meteorites' with a list of meteorites represented in the collection and from then on such time as he had to spare from the management

of the Department was devoted to the description and analysis of the meteorites, and to maintaining records of the place and circumstances of each fall or find.

However, he did make several further contributions to descriptive mineralogy. His paper 'On cubic crystals of graphitic carbon', which he named 'cliftonite', was the outcome of his study of the Youndegin meteorite (Fletcher, 1887*a* and *b*). These little cubes are now known to be pseudomorphs in graphite after a cubic mineral, probably diamond (Hey, 1938; Grenville-Wells, 1952).

Fletcher and Miers (1887) supplied chemical analyses of the feldspar crystals from Kilimanjaro sent by Sir Harry Johnston, and showed that they contained over 4.5% potash. Miers, redescribing the crystals and their optical properties, showed them to belong to the group which included the anorthoclase of Rosenbusch (Miers, 1886; Fletcher & Miers, 1887). It is interesting to note that J. J. H. Teall had observed that these crystals resembled the feldspar insets in rhombenporphyr from Christiania. In the same year, Fletcher identified and described crystals of cuprite and cerussite formed on and around Roman coins buried for about 15 centuries (Fletcher, 1887*c*).

In 1889 a specimen of percylite from a mine in Atacama attracted Fletcher's attention, because of its rarity. Other specimens from the same mine were obtained and, in addition to many interesting lead and copper minerals, he picked out some very small hexagonal crystals, less than 1 mm in diameter, some of which he succeeded in measuring. From his measurements he identified them as caracolite, a new mineral described in the previous year by Professor Websky. He also found in a cavity less than 2 mm in diameter some minute, elongated, colourless crystals. Though less than 1 mm in length and about $\frac{1}{6}$ mm wide, he obtained good measurements of these and provided excellent drawings. From simple wet and dry tests carried out with great skill on single crystals, he concluded that they might be an oxychloride of lead, but could not correlate the angles with those of any known mineral of that composition. Believing it to be necessary 'for purposes of reference at least' to give a name to it he named it daviesite, in honour of his colleague Thomas Davies (Fletcher, 1889); the crystals have recently been identified as hemimorphite (P. G. Embrey, pers. comm., 1963).

Fletcher returned once more to work on rare and new minerals in 1892 when Mr Joseph Baddeley offered to present to the Museum one of the eight or nine pebbles of the new mineral recently named geikielite by Allen B. Dick of the Geological Survey (1893; paper read 14 June 1892). Fletcher noticed among these few pebbles one which showed some crystal faces and this he selected for the Museum. He succeeded in measuring the faces and determining the optical properties and, by a long series of qualitative tests, proved the material to be zirconia. He named this new mineral baddeleyite (Fletcher, 1892*b*; 1893*a*,*b*). By an odd coincidence, Dr E. Hussak had described, under the name brazilite, crystals occuring in jacupirangite from Sao Paulo and at first believed to be orthite but later shown, by Professor Blomstrand, to be 'almost pure zirconia'. Crystal measurements had confirmed the identity of brazilite and baddeleyite and Dr Hussak withdrew the former name (Hussak, 1892; 1895).

Fletcher's later work was almost wholly devoted to meteorites but he also wrote several articles on the precious stones of the Bible (Fletcher, 1893*e*), the principal one being in a guide to an exhibition at the Museum in connection with the tercentenary of the publication of the Authorized Version in 1611 (Fletcher, 1911).

Although not trained as a geologist or petrologist he wrote in 1895 'An introduction to the study of rocks'. This gave references to an exhibit in the Mineral Gallery and was also a guide to the exhibited series of rocks. Fletcher described it as an attempt 'to give, from a Museum point of view, a simple sketch of the relationship of rocks indicating at the same time all the more important characters and pointing out their significance'. It ran to six editions.

Henry Alexander Miers had joined the Department in 1882. He had gone up to Oxford from Eton with a classical scholarship but he read mathematics as well and, later, hearing that there was to be a vacancy for an additional Assistant in Mineralogy, he decided to read for that also. He was the only pupil in the subject at that time and Professor Maskelyne used to go up for week-ends to give him 'lectures' in crystallography and mineralogy. Miers evidently worked to good purpose for he defeated his only serious competitor, Frederick Sanderson, later to become

the famous Headmaster of Oundle. Miers had also spent two vacations in Cambridge studying there with W. J. Lewis, and had worked under Groth at Strasbourg for another three months. Thus he arrived at the British Museum tolerably well equipped and was immediately appointed as a First Class Assistant.

Walter Flight, the chemist, died only three years after Miers' appointment; he was a great loss to the Department. Fortunately the vacancy was filled by the appointment in 1887 of George Thurland Prior, who had graduated from Magdalen College, Oxford, with first class Honours in both Physics and Chemistry in 1886. He had also studied chemistry for some months with A. Classen at Aachen. Prior was put in charge of the chemical laboratory and at once began collaboration with Fletcher and Miers, undertaking the analytical work on the minerals and meteorites which they were investigating. This collaboration continued with excellent results when L. J. Spencer joined the staff in 1894.

Whereas Fletcher, as his contribution to the 'Crystallographic Catalogue' had studied the elements and sulphides, Miers seems to have started his part of the catalogue with sulpharsenites, sulphantimonites, and so forth, and this led to his early paper 'On the crystalline form of meneghinite' (Miers, 1884*b*), which was followed by 'The crystallography of bournonite', read before the Mineralogical Society in 1884 (Miers, 1884*d*).

Meneghinite was known only as a very small crystal with few end faces, difficult to measure satisfactorily. Using a Fuess horizontal-circle goniometer Miers succeeded in measuring several crystals with good results. He showed that the mineral crystallizes in the orthorhombic system but that its parameters could not be made to agree with those of jordanite, although the two minerals were analogous in composition. Miers pointed out, however, that there was a relationship between his meneghinite parameters and those of stephanite, $4[Ag_5SbS_4]$. The formula now proposed for meneghinite is $2[CuPb_{13}Sb_7S_{24}]$, jordanite being $2[Pb_{14}As_7S_{24}]$. It is considered that the small amount of Cu, about 2%, is an essential constituent (Berry & Moddle, 1941).

The paper on bournonite took, as Professor Watts remarked in his Jubilee Address to the Mineralogical Society, a monographic form. It contained a list of all previous publications on the mineral, as well as a complete list of crystal forms with comments and including 29 new forms found by Miers during his investigation, all with supporting measurements. His table of interfacial angles gave a list of over 1000 angles and the paper ended with a full discussion of the twin growths, particularly of the wheel-shaped groups from Herodsfoot, and the Radelerz from Kapnik, all well represented in the British Museum Collection.

After the completion of this paper Miers seems to have devoted his research work to the group of 'red silver ores' (Rothgültigerz), of which the most important members are proustite and pyrargyrite. The main paper was not read until May 1888 but in the previous year he and Prior read a paper 'On a specimen of proustite containing antimony' (Miers & Prior, 1887). Miers had also used some of his collected data on proustite and pyrargyrite to illustrate a short paper 'On the use of the gnomonic projection' (Miers, 1887). The paper, with Prior, was a study of 'a magnificent piece of proustite from Chanarcillo, Chili'; brilliant lustrous prisms in a radiating group. The sensitivity of this specimen to light is such that it has to be kept in the dark. Miers obtained good measurements on three scalenohedral crystals whilst Prior made analyses and determined the specific gravity. The analyses were made on two samples, one from the base of the specimen and another on the measured crystals and other small crystals of similar appearance.

The authors concluded that the antimony is very unevenly distributed in the specimen: 'it is even conceivable that the surface of the crystals may contain no antimony; but however that may be, it is certain that in the crystals here analysed the presence of more than one per cent of antimony has no appreciable effect upon the rhombohedron angle'. Whether this always held good would perhaps be decided, they suggested, by the examination of a large number of specimens, a task on which the authors were then engaged.

The completion of this task resulted in the great paper modestly entitled 'Contributions to the study of pyrargyrite and proustite' (Miers & Prior, 1888). It was on similar lines to the bournonite paper but there were now two related species to consider and a vast number of measurements of angles and forms recorded in the published papers by earlier authors and by Miers himself. Summarizing their results, they show that proustite and pyrargyrite are two distinct species with

sufficient differences in the rhombohedron angle, specific gravity, colour and streak, to enable them to be distinguished. Pyrargyrite is shown to be hemimorphic and proustite probably so. Both species are strictly rhombohedral: 'no typical forms occur in both the direct and inverse positions'. Typical forms are defined as those which occur as bright, independent faces. Miers gives lists of typical forms for each of the two species: there are 36 for pyrargyrite and only 12 for proustite; of these 8 are common to both species. Some of the typical forms have rather high indices; in pyrargyrite there are six with one or more indices higher than 8; in proustite only one (13.2.3). Twin growths are studied very closely and the laws stated; there are five twin laws of which three operate in both species. The last part of the crystallographic study is devoted to measurements of striated (and curved) zones and of vicinal faces, and the distribution of the vicinal faces is discussed.

Prior made very careful analyses of fifteen selected specimens, and determined the specific gravity of each. For the analysed specimens the rhombohedral angle also is recorded and it is concluded that 'the variations in the rhombohedral angle among the whole series of pyrargyrites analysed fall within the irregular variations on individual specimens, and cannot be attributed to the presence of varying quantities of arsenic; the same is true of proustite containing antimony'. And further: 'no certain connection can be traced between the presence of arsenic in pyrargyrite and the habit or appearance of the crystals; specimens of identical appearance sometimes contain a small percentage of arsenic and are sometimes free from it; and some pyrargyrite of rather light colour is found to contain no arsenic' (Miers & Prior, 1888, pp. 99–100).

The last paper in this series, 'the red silver ores', was 'On xanthoconite and rittingerite, with remarks on the red silvers' (Miers & Prior, 1893). In the meantime Miers had published short papers on polybasite and aikinite (of Chapman) (Miers, 1889*b*), on stephanite, demonstrating its hemimorphism, and kaolinite (Miers, 1890*a*), and on a new mineral, sanguinite, a sulpharsenite of silver (Miers, 1890*b*).

Xanthoconite, $16[Ag_3AsS_3]$, and rittingerite were believed to be two distinct minerals but neither had been correctly determined in respect of composition, crystal form, or physical characters. Miers made a careful study of both minerals, with the usual careful chemical analyses by Prior, which showed that the two minerals have the same composition as far as could be ascertained with the limited material available. A complete analysis of rittingerite was not possible but silver was determined quantitatively on 3.8 mg and found to be practically identical with the silver content of xanthoconite.

In the complete series of the red silvers the rhombohedral pair proustite and pyrargyrite correspond to xanthoconite and fireblende (pyrostilpnite), which are monoclinic. Fireblende was the only member of the series of which material was not available in the Museum collection for as thorough an examination as had been made of the other members, but the data provided by Luedecke (1882) were available. Miers observed 'that these two minerals, xanthoconite and pyrostilpnite, present a very interesting example of isomorphism in the same system with different orientation. They both crystallize in rhombic-shaped plates, having an angle of 54°, and belonging to the monosymmetric system: but whereas in xanthoconite the plane of symmetry is perpendicular to the plate and parallel to its longer diagonal, in fireblende it is parallel to the plane of the plate'. These findings are confirmed by a much more recent study of the two minerals, with X-ray measurements, by the late M. A. Peacock (1950).

It is interesting to note that for the determination of the optical properties of xanthoconite Miers constructed a stage goniometer for the microscope; it was later manufactured by Troughton & Simms. During this period and outside his official Museum duties, Miers was an instructor in crystallography in the chemical department of the City & Guilds College, where he developed a student's goniometer for use in his classes (Miers, 1891*b*).

Miers' study of the vicinal faces in proustite and pyrargyrite aroused his interest in crystal growth and, about 1892, he commenced a systematic study of the formation of crystal faces, working at home and at night. A preliminary report on this work was made in a paper read to Section C (Geology) of the British Association at its meeting at Oxford (Miers, 1894*b*); all the later work was carried out at Oxford where Miers had been appointed Waynflete Professor of Mineralogy in 1895. The main results were presented to the Royal Society (Miers, 1903) but

work on crystal growth and related problems (parallel growths and spontaneous crystallizations) was continued at Oxford for several years in conjunction with his students: Miss Florence Isaacs, T. V. Barker, and J. Chevalier.

The paper read in 1894 was entitled 'A new method of measuring crystals and its application to the measurement of the octahedral angle of potash alum and ammonium alum'. The alums were known to show large variations in the octahedron angle, and it was also known that the octahedron was often replaced by vicinal faces. Miers set out to ascertain 'whether progressive variations can be traced during growth of a single crystal, and whether some or all of the octahedron faces change their character in space if the crystal be held fixed during growth'.

To test these questions Miers designed an inverted goniometer with which he could measure with great accuracy the faces in an octahedron zone while the alum crystal, fixed on a crystal holder, was actually growing in a saturated solution of its own composition. The solution was contained in a glass tank provided with parallel plate-glass sides. The tank could be raised or lowered as required so that the crystal could be completely immersed in the solution while it was being measured.

In order to determine the positions of the vicinal faces in relation to the octahedral face which they are replacing he designed a micrometer eyepiece which could be fitted to the telescope of the goniometer. Thus, when an eyepiece of sufficient strength showed that what appeared to be a single image was in reality three over-lapping images formed by vicinal faces, the micrometer eyepiece enabled the positions of each of the three vicinal faces to be established. From the mutual inclinations of the vicinal faces it was possible to calculate accurately the octahedron angle of the alum crystal; it was found to be $70° 31\frac{3}{4}'$, and not to be subject to variation as had been supposed from measurements made by the earlier worker, Reinhard Brauns, and others.

Miers also showed that the growth of the crystal does not take place by the deposition of parallel plane layers but that new (vicinal) faces are constantly developed. Moreover, the vicinal faces developed vary with the concentration of the solution in which they are grown and thus give rise to variations in the measured angles observed and hitherto considered as anomalous. Miers foresaw that 'a further study of the faces developed during the growth of crystals will . . . lead to a better understanding of the reasons why a simple face like the octahedron should not be a surface of equilibrium, and of the relations between the vicinal planes and the structure of the crystal'.

The full results of this work on the growth of alums and of other cubic crystals were published by the Royal Society (Miers, 1903). In the conclusions it is pointed out that the faces which actually occur on a crystal are not those with simple indices, like (111), which have great reticular density of 'particles', but those with complex indices, like vicinal faces, which have very low reticular density and that this is perhaps connected with the need for 'particles' of the water of solution to be able to escape from the growing crystal face.

Thomas Davies, who had been on the staff since 1857, the year of Story-Maskelyne's appointment as Keeper, died in 1892. The vacancy thus caused was not filled until 1 January 1894, when Leonard James Spencer was appointed as an Assistant.

Spencer was highly qualified as a mineralogist and chemist. From Bradford, at the age of sixteen he had obtained a Royal Exhibition to the Royal College of Science, Dublin, gaining first class honours in chemistry in 1889. Proceeding then to Sidney Sussex College, Cambridge, he took Firsts in both parts of the Natural Sciences Tripos, taking geology for Part II and winning the Harkness Scholarship in 1893. The examination for the vacancy in the Department of Mineralogy was held that summer and Spencer was the successful candidate, the runner-up being (Sir) William J. Pope, later to become Professor of Chemistry at Cambridge.

At the Keeper's request—was it nearly a command?—Spencer went to Munich to study for three months under Professors Paul Groth and Weinschenk. This he did at his own expense, in fact using the Harkness Scholarship money for the purpose. This study in Germany, undoubtedly very valuable, delayed his actual appointment by some three months and may have affected his position in later years when it came to promotion to First Class Assistant.

Spencer began his part of the work on the Crystallographic Catalogue on the sulpharsenates and sulphantimonates and in a little over a year, on 2 April 1895, he read a paper on enargite

$2[Cu_3AsS_4]$ (Spencer, 1895). This was drawn up on the lines of Miers' bournonite paper: a listing of the previous literature; a list of known forms; measurements establishing new forms; very careful, critical measurements of the prism angle, and of the angle (001):(011) from which the parameters were calculated; twinning, establishing (320) as the twin plane; and, then, a description of the mineral clarite, proving its identity with enargite, and a discussion of the several other minerals similar in composition to enargite. These are luzonite, which Spencer showed might be a massive form of binnite, and regnolite, which he thought might also be referred to binnite. The name regnolite is now regarded as a synonym of tennantite, and binnite a variety of the same mineral.

This work on binnite initiated close collaboration with Prior on binnite, tennantite, tetrahedrite and the fahlerz (Prior & Spencer, 1899). In this paper the crystallography of binnite was based on the examination of about 60 specimens obtained as a result of blasting operations in the Binnenthal, and mostly supplied by R. H. Solly. Goniometric measurements were made on 24 crystals and nearly as many fragments of crystals, and Prior analysed eleven of the measured crystals.Together these studies proved the identity of the binnite (of Des Cloizeaux) from Binn with the Cornish tennantite and established the formula as Cu_3AsS_3. A partial analysis on two crystals which showed a black streak instead of the usual chestnut brown gave Ag 4.77%, Fe 3.68%.

The second part of this paper, read on 20 June 1899, on the composition of the fahlerz gave an introduction to previous literature followed by the results of analyses of three crystals chosen very carefully for purity. For each of these crystals the crystallography, physical characters, and mineral associations were described. Their compositions were shown to agree with the formula $3[(Cu,Ag)_2S(Sb,As)_2S_3]$ and an important suggestion was made as to the role of the small amounts of sulphides of iron and zinc in the constitution (op. cit; p. 203). Finally the new formula was tested by reference to the results of eighteen previous analyses of minerals variously named as tetrahedrite (Rose, 1829), coppite (Bechi, 1863; D'Achiardi, 1873), aphthonite (Nilson, 1877), fahlerz, and tennantite.

The fruitful collaboration between Spencer and Prior continued, Prior supplying the chemical analyses for a series of joint papers. Between 1897 and 1899 three more papers were published on the sulphantimonites of lead and silver: zinckenite and wolfsbergite from Wolfsberg in the Harz (Spencer, 1897*b*); plagionite, stephanite, enargite, and anglesite (Spencer, 1897*c*); and plagionite, heteromorphite, and semseyite (Spencer, 1899). The last of these contained important suggestions on the structural formula and on the explanation of the imperfect crystal forms found in intermediate members of the plagionite-semseyite group.

After this, except for a note on 'feather-ore' (Spencer, 1907*a*) (see p. 57) attention was turned to the many other interesting minerals which were reaching the Department from various famous mining districts, largely through the good offices of the mining men whom Prior and Spencer had interested in the Collections. This work resulted in a succession of papers between November 1897 and April 1909.

The first of these was a short paper on augelite from a new locality in Bolivia in which he recorded more accurate crystal measurements, refractive indices, and specific gravities than hitherto (Spencer, 1898*a*; see also Prior & Spencer, 1895). A paper followed on crystallized stannite from Bolivia, based on specimens collected by Sir Martin Conway (Spencer, 1901*a*); crystals of this mineral had not been described previously. Spencer succeeded in measuring some twelve of them, and he figured and described elegant interpenetrant pseudo-cubic twins, pointing out the close correspondence between the crystallographic characters of stannite and chalcopyrite. This is the more interesting as Prior's analyses, the first ever made on crystallized stannite, showed that the formula could be written as $Cu_4SnS_4 + Fe_2SnS_4$, representing an orthostannate, or as $CuFeS_2 + CuSnS_2$, showing a possible relation with chalcopyrite, $CuFeS_2$. The formula accepted by Hey (1950) is $2[Cu_2FeSnS_4]$, chalcopyrite being $4[CuFeS_2]$.

Spencer kept up his work on minerals from Bolivia for several years and in 1907 he published 'Notes on some Bolivian minerals' with chemical analyses by G. T. Prior (Spencer, 1907*b*). These notes were arranged under seventeen headings describing different species. Semseyite was recorded for the first time from Bolivia and an analysis provided by Prior. Also published for the

first time was an analysis made in 1897 of measured crystals of jamesonite. Crystals of andorite showing new crystal forms were described and the systematic position of this mineral discussed. One interesting relationship brought to notice is that for the series andorite, diaphorite, freieslebenite, it is shown that writing the composition for this series as $n\mathrm{RS} . \mathrm{Sb_2S_3}$, an increase in n, 1, 2, $2\frac{1}{2}$, is accompanied by an increase in the length of the c axis, comparable to the relationship shown in the humite, chondrodite, clinohumite series.

Other minerals described are: chalcostibite, augelite, vivianite, tetrahedrite, valentinite, cassiterite, tourmaline (frequently overlooked in Bolivian mines on account of its unusual pale green colour), fluorite, apatite, miargyrite, jarosite, chalybite, and enargite. The tetrahedrite is found in two distinct habits; one tetrahedral, steel-grey and usually twinned; the other iron-black, and resembling tennantite ('binnite') from the Binnenthal. An interesting find is a tetrahedral crystal on the faces of which pseudo-cubic crystals of stannite are in parallel growth. Crystals of valentinite, carefully detached from the specimens, were measured both by Spencer and by Herbert Smith, who also determined the refractive indices, whilst Prior made an analysis on pure, crystallized material which confirmed the accepted formula, $\mathrm{Sb_2O_3}$.

Another famous mine which provided material for several papers was Broken Hill, New South Wales. The rare minerals marshite, miersite, and iodyrite from this mine were described in 1898 (Spencer, 1898*b*). Crystals of CuI had been discovered by C. W. Marsh in 1892 and named marshite by Professor A. Liversidge later in the same year (Liversidge, 1892); miersite, 'a cubic tetrahedral modification of AgI containing some CuI, isomorphous with marshite', had been described by Spencer (1898*b*). He had now available better crystallized material of both minerals, of which he described the crystallographic and physical characters, and for miersite, the interesting changes undergone on heating. Changes on heating were also described for cleavage plates of the silver iodide, iodyrite, and for this mineral two types of crystal are described: hexagonal plates or short prisms and also pseudo-cubic crystals consisting of four rhombohedral crystals in twin relationship. These 'are in fact mimetic crystals of iodyrite with the same external form as miersite and marshite'. The paper concludes with a thoughtful discussion of the mutual relations of the three minerals (Spencer, 1901*b*). Finally, analyses of both miersite and marshite made by Prior on carefully selected material were published a year later (Prior, 1902). They confirmed the compositions $4\mathrm{AgI} . \mathrm{CuI}$ and CuI which Spencer had deduced from his qualitative tests.

Other papers published by Prior and Spencer concerned stanniferous argyrodite from Bolivia and the identity of the so-called 'crystallised brongniardite' with argyrodite-canfieldite (Prior & Spencer, 1898); the identity of andorite, sundtite and webnerite (Prior & Spencer, 1897); and the cerargyrite group and iodembolite (Prior & Spencer, 1902).

Prior also made analyses of minerals for Dr E. Hussak of the Geological Survey of Sao Paulo, Brazil, for Dr F. Zambonini of the University of Naples, and for Dr A. K. Coomáraswámy.

In five papers in collaboration with Prior, Dr Hussak described five new minerals from Brazil: lewisite, a titano-antimonate of calcium and iron related both to perovskite and to the calcium antimonates, atopite and roméite (Hussak & Prior, 1895); derbylite, an antimonate of iron (Hussak & Prior, 1896); and tripuhyite, another new antimonate of iron (Hussak & Prior, 1897). All these three minerals were found in gravels at the cinnabar mine of Tripuhy, near Ouro Preto, but the country rock is muscovite schist associated with itabirite. Zirkelite was found associated with baddeleyite and perovskite in the magnetite pyroxenite of Jacupiranga, Sao Paulo. A complete quantitative analysis made on additional material collected by Hussak proved the presence of thorium, cerium, and uranium along with the titanium and zirconium revealed by Prior's earlier analysis. The formula suggested was $R\mathrm{O}\,(\mathrm{Zr,Ti,Th})\mathrm{O_2}$ where R represents Ca and Fe (Hussak & Prior, 1895; Prior, 1897). Senaite, found as rough, rhombohedral crystals in the sand of Diamantina, Minas Gerais, was shown to have a composition near $(\mathrm{Fe,Pb})\mathrm{O} . 2(\mathrm{Ti,Mn})\mathrm{O_2}$ with PbO 10.5% (Hussak & Prior, 1898). M. H. Hey, however, regards it as a possible variety of ilmenite with the formula $(\mathrm{Fe,Mn,Pb})\mathrm{TiO_3}$ (?) (pers. comm., 1976).

A much more interesting mineral described in 1899 is 'florencite, a hydrated phosphate of aluminium and cerium earths' (Hussak & Prior, 1900). This mineral was found at three localities in Brazil: in the cinnabar-bearing gravels at Tripuhy associated with xenotime and monazite, and lewisite and derbylite; in diamond-bearing sand near Diamantina; and from another locality

at which the yellow topaz is found, near Ouro Preto. At this last locality the florencite is a microscopic constituent of micaceous schists. That the mineral was a phosphate of cerium earths was shown by Dr W. Florence, after whom the mineral is named. He had suggested that the new mineral had a close relationship with hamlinite; this was confirmed by Prior in a paper read six months later (Hussak & Prior, 1900). After reviewing analyses of this group of minerals—and giving a caution against over-estimation of the exactness of mineral analyses when calculating formulae—he suggests that the five minerals listed in the title form a natural group of rhombohedral minerals:

Hamlinite	$2SrO . 3Al_2O_3 . 2P_2O_5 . 7HO.$
Svanbergite	$2SrO . 3Al_2O_3 . P_2O_5 . 2SO_3 . 6H_2O.$
Plumbogummite	$2PbO . 3Al_2O_3 . 2P_2O_5 . 7H_2O.$
Beudantite	$2PbO . 3Fe_2O_3 . P_2O_5 . 2SO_3 . 6H_2O.$
Florencite	$Ce_2O_3 . 3Al_2O_3 . 2P_2O_5 . 6H_2O.$

In a later paper on the connection between the molecular volume and chemical composition of some crystallographically similar minerals, Prior used the hamlinite-florencite-beudantite-alunite group as an example, and gave a long list of further examples. He showed how this connection between molecular volume and composition can be used to suggest appropriate formulae. Thus, rutile $2(TiO_2)$ written as Ti_2O_4 or $TiTiO_4$ brings it into correspondence with $ZrSiO_4$, and the molecular volumes of the two minerals would be 38 and 39, respectively (Prior, 1903*a*).

Strüverite had been described as a new mineral in 1907 by Dr F. Zambonini, who had shown it to contain niobium and tantalum, with titanic oxide, iron oxide, and traces of manganese. Prior studied the known difficulties of separation of niobic, tantalic, and titanic acids and went to great pains to improve the technique. He established the composition of strüverite, and also made two analyses of ilmenorutile and discussed the close relationship between the two minerals (Prior & Zambonini, 1908). Another paper with Zambonini was 'On the identity of guarinite with hiortdahlite'. Zambonini described the crystallography of the two minerals and reviewed published analyses, etc, concluding that the two were identical; Prior's analysis of guarinite confirmed this (Zambonini & Prior, 1909). This conclusion was substantiated later, though the two minerals are now regarded as separate species, clino- and orthoguaranite (Cesàro, 1932).

Prior also collaborated with Dr A. K. Coomaraswamy in his description of the new mineral, serendibite, found as small blue grains at a granulite-limestone contact in Ceylon. Prior's analysis showed it to be a borosilicate of alumina, magnesia, and lime (Prior & Coomáraswámy, 1903). It has since been discovered in metamorphic limestone in Warren Co., New York. An analysis by Larsen and Schaller (1932) included a quantitative determination of B_2O_3 which Prior had been unable to make on the very small amount of material—0.57 g altogether—available to him.

Prior's independent papers in order of publication are: 'note on connellite from a new locality', describing a specimen from Namaqualand given to Tom Davies in 1861 and presented by him to the Museum in 1887 (Prior, 1889); 'on zinc sulphide replacing stibnite and orpiment . . .': this paper described material from Felsöbánya and also contained analyses of stephanite from Copiapo and from Cornwall, and of polybasite from Mexico. Miers contributed a list of forms identified on the Cornish stephanite (Prior, 1890); and a paper on fergusonite from Ceylon giving two analyses of a pebble from the same group as that in which Fletcher discovered the new mineral baddeleyite (p. 49). These again involved the determination of niobium and tantalum, and uranium, yttrium and erbium. They showed more uranium than Rammelsberg's earlier analysis of fergusonite from Ytterby. Prior described the remarkable bright red glow which appears when a small splinter of the mineral is heated to redness; a phenomenon also exhibited by gadolinite (Prior, 1893).

Prior's (1897) paper on zirkelite, read in 1896, has been referred to above. A short paper on 'sphaerostilbite' showed the specimens so labelled in the Museum collection to be thomsonite (Prior, 1898). Another paper brought together notes on 'Minerals from Swaziland', collected

and presented by Mr Sidney Ryan from the Embabaan district. The most important is of a specimen which analysis showed to be related to euxenite but which in crystal habit resembles the 'aeschynite' from Hitterö described by Brögger (Prior, 1899). This mineral was later named priorite by Brögger (1906, pp. 110–116).

A paper read in 1902 collected notes on analyses of several minerals. An analysis of 'kilbrickenite' from Kilbricken mine, Co. Clare, showed it to be identical with geocronite; also included were new analyses of carefully selected examples of the minerals miersite and marshite from Broken Hill, N.S.W., described by Spencer (1898*b*); and an analysis of chalcopyrite of apparently cubic habit (Prior, 1902).

A new mineral, teallite, was discovered as thin, graphite-like folia in kaolin in specimens from Bolivia forming part of the Hohmann Collection of South American minerals (see *Mineralog. Mag.* **13***: 382*). Prior's analysis showed it to be a sulpho-stannite of lead, $2[PbSnS_2]$. Prior measured the crystals himself using Herbert Smith's newly constructed three-circle goniometer, which must have been quite exciting. He realised that there might be a relationship between this new material, and franckeite and cylindrite from Bolivia, both being known to contain lead, sulphur, and tin. Prior demonstrated the relationship by making complete analyses of both minerals (Prior, 1904).

In another short paper he established the formula of dundasite from North Wales as $PbO.Al_2O_3.2CO_2.4H_2O$. (Prior, 1905*b*). This mineral, found on cerussite by Mr G. J. Williams, was new to Britain. Prior's last paper in this long series, recording his numerous analyses published either independently or in collaboration with others, brings together three more analyses of minerals from the Binn valley, all collected by R. H. Solly. They are of seligmannite, 'binnite', and a green muscovite (fuchsite). The analysis of seligmannite, the first complete quantitative analysis of this mineral, confirmed Baumhauer's suggestion, based on its crystallographic characters, that it would prove to be isomorphous with bournonite. The 'binnite' analysis showed this specimen, 'a large cubic crystal with faces 15 mm across', to be tennantite containing a large proportion of zinc (7.76%). The paper was read to the Mineralogical Society in June 1908 (Prior, 1910).

In addition to his work in the chemical laboratory Prior, in common with Spencer, had work to do in keeping up-to-date the hand-written registers of acquisitions to the collections and in addition had taken over from Thomas Davies the care of the collection of rocks. In this connection he had himself contributed important papers (published between 1897 and 1903) on the petrography of some of the early collections of rocks, notably from the Antarctic, Abyssinia and East Africa, and several of the Atlantic islands.

His review of the volcanic rocks of East Africa and the Atlantic Islands showed their relationship to those of the Auvergne, the Eifel, the Bohemian Mittelgebirge, and especially the rocks of Pantelleria, and he came to the conclusion that 'of the four great volcanic chains running north to south, the great Atlantic chain with its European branches, and the minor chain along the east coast of Africa, including Madagascar, are characterized by the association of basalts and alkali-rich phonolitic rocks, whereas in the two other great Pacific-chains . . . andesites are the prevailing lavas'. Thus he was making, in 1902, perhaps the first suggestion of what later came to be spoken of as the Atlantic and Pacific Provinces of igneous rocks (Prior, 1903*b*).

His last petrological contribution described the alkali lavas of Mt Nimrud, on the west side of Lake Van, from an early collection made by Dr Felix Oswald (1905), showing that they were similar to some of the lavas of the East African Rift Valley. He made chemical analyses of three of these rocks to confirm this point, and noted that Oswald had remarked that Mt Nimrud is 'on the great line of fracture which cuts across the Armenian folds and extends through the Red Sea to the East African Rift Valley . . .' (Prior, 1928).

During this period Spencer turned his attention to the study of tellurides from Australia. The specimens had been presented to the Museum at various times since 1897 and much of the material had formed part of the collection specially prepared for the Paris Exhibition of 1900 and later shown at the Colonial Exhibition in London in 1902. The minerals described were: calaverite, sylvanite, petzite, coloradoite, altaite, and the minerals now known to be mixtures,

'kalgoorlite' and 'coolgardite'. Brief descriptions were given of the associated minerals and the paper was read in June 1902 (Spencer, 1903*a*).

Several short papers by Spencer were published between 1903 and 1908, on crystalline forms of carbides and silicides of iron and manganese (Spencer, 1903*b*); irregularly developed crystals of zircon (sp. gr. 4.0) from Ceylon (Spencer, 1904); phenakite and other minerals from German East Africa (Spencer, 1906)—a note on 'feather ore' [Federerz]; identity of domingite (= 'warrenite') with jamesonite (Spencer, 1907*a*)—and, with H. J. Johnston-Lavis, on chloromanganokalite, a new Vesuvian mineral. To this Spencer contributed data on the crystallographic and optical characters, and notes on some associated minerals (Johnston-Lavis & Spencer, 1908).

In the paper on zircon crystals Spencer (1904) described the peculiar optical properties of the crystals, the variations and changes in specific gravity, and the change of optical properties on heating from dark brown uniaxial positive to grass-green biaxial. He quoted A. H. Church and S. Stevanović on the suggestion that in one of the varieties of zircon there may be, instead of zirconium, another, closely related element. The paper on phenakite, besides noting the large size of the crystal (about 1.5 × 1 cm) also mentions sheets of muscovite measuring 19 × 12 cm when trimmed; they were first described by Bornhardt (1900).

The note on 'feather-ore' (1907*a*) reviewed the accounts of the various minerals which had been identified as 'Federerz' and showed that several quite different minerals were involved. One of these might be stibnite but most 'feather-ores' contain lead, antimony, and sulphur. The minerals are of two kinds: one is 'brittle', with a cleavage perpendicular to the fibres (jamesonite); the other is flexible and may be one of at least four different minerals. It was not possible to identify such tiny fibres because fibres of more than one kind may be intermingled. These flexible 'feather-ores' may be grouped, Spencer considered, in a 'natural history group to which the name plumosite may conveniently be applied'. They must be removed from jamesonite. In the course of the discussion it is shown that 'domingite' from Colorado (= warrenite) is identical with jamesonite.

Another important paper by Spencer was written on a group of zinc phosphate minerals found in cavities and caves in low hills, 'kopjes 1 and 2', then recently discovered in the neighbourhood of deposits of lead and zinc ores at Broken Hill, Zimbabwe. These kopjes are now famous for the discoveries made there of bone-breccias and the remains of early man, including the Rhodesian skull (Spencer, 1908). The material in which the crystallized zinc phosphates were found was sent to the Museum by Mr Percy C. Tarbutt, and other material was made available by the British South Africa Company. Altogether fifteen different species are recorded: of these the most interesting is hopeite, a mineral only once discovered previously. It was first described and named by Sir David Brewster (1823) from a specimen from a zinc mine at Altenberg, near Aachen. Spencer, describing the crystals now available, showed that there are two modifications, α-hopeite and β-hopeite, identical in composition but differing markedly in optical characters and the rates at which water is lost on heating. The composition is $Zn_2P_2O_8 . 4H_2O$, as determined by Spencer's analyses. He also described two new minerals: parahopeite, identical with hopeite in composition but distinct in symmetry and optical characters; and tarbuttite, $Zn_3P_2O_8 . Zn(OH)_2$, a basic zinc phosphate. Also described are large crystals and massive specimens of descloizite, vanadinite, and pyromorphite; also hemimorphite and calamine, hydrozincite, and cerussite, the last forming beautiful, large, splendent crystals. All these are now well represented in the Museum and doubtless also in most good mineral collections. Spencer and F. N. Ashcroft both visited the locality after the International Geological Congress at Capetown in 1929.

Still another paper on a group of minerals from one mine, this time in England, was 'on the occurrence of alstonite and ullmannite . . . in a barytes-witherite vein at the New Brancepeth Colliery near Durham' (Spencer, 1910*a*). Alstonite had been recorded at only two mines in England and never within the past fifty years. Spencer found some specimens in a dealer's stock and by a piece of detective work traced them to the New Brancepeth baryte vein. The alstonite occurs in acute six-sided pyramids; they are rose-tinged in the mine but quickly lose this colour on exposure. The other very rewarding find in the mine was ullmannite, NiSbS, discovered for the first time in Britain. It occurred in crystals of two habits: cubic and octahedral; it has good

cubic cleavage and was found sometimes in parallel growth with galena. Baryte, often in large transparent crystals, and witherite, both as crystals and as nodular masses, are fully described.

In January 1910 Spencer read to the Mineralogical Society a paper on the weight of the Cullinan diamond and on the value of the carat weight. He had been struck by the varying weights reported for this, at that time the biggest known diamond, and he made a thorough examination of the reports and actually checked the weights used in the various offices where the diamond had been weighed. At the same time he reviewed the variations of the carat weight as used in various countries, including the metric carat recently adopted in France (Spencer, 1910*b*). He followed this paper the next year with one recording the weights of the larger diamonds, giving particulars of 26 stones found between 1869 and 1905, when the Cullinan was found, with place and date of find, weight of the rough stone, and the weights of the largest cut stones obtained from each (Spencer, 1911*a*).

It was also in 1910 that Spencer did some important work on orthorhombic crystals from a Cornish tin furnace which C. O. Trechmann had named 'β-tin' in 1879. Analyses by J. H. Collins gave the composition as metallic tin. It had been noticed that crystals of stannous sulphide gave the same parameters as Trechmann's for 'β-tin'. Spencer was able to re-examine the original specimens and showed that Trechmann's crystals contained much sulphur, and were in fact SnS. Collins had taken crystals for analysis from the same specimen but they were of metallic tin and not the same as those measured by Trechmann. Spencer did not publish his work until much later, after Trechmann's death (Spencer, 1921*a*).

In this paper Spencer also gave a description of the orthorhombic SnS, and of the tetragonal iron stannide, $FeSn_2$, and of a rhombohedral tin arsenide, Sn_3As_2. These last two descriptions were the product of work done in collaboration with J. E. Stead on the ternary alloys of Sn–Sb–As (Stead & Spencer, 1919).

In the course of the work on these alloys Stead had observed some remarkable, but microscopic, crystals of one of the alloys in the form of segments of spherical shells and he asked Spencer whether similar forms were known among minerals. Spencer collected what information he could at that time, giving some illustrations of curved forms in crystals found in the Mineral Collection including, for example, helical twist in stibnite crystals (Spencer, 1921*c*). J. E. Stead also supplied crystals from an iron furnace of the iron phosphide (rhabdite), which Spencer described (Spencer, 1916*a*). Rhabdite was discovered in 1864 as a constituent of a meteorite and it had also been prepared artificially. Spencer was able to establish the tetragonal symmetry of these tiny crystals.

In 1907 and during part of 1908 Fletcher was ill and away from the Department. He recovered and in 1909 was appointed Director of the Museum in succession to Sir Ray Lankester, while G. T. Prior became Keeper of Minerals. From 1907 onwards any time that Prior could spare from the administration of the Department was spent in the chemical laboratory, but now all his analytical and petrographic work was devoted to meteorites and their classification (Spencer, 1936). The vacancy caused by Fletcher's appointment as Director and Prior's promotion to Keeper was filled by the appointment as an Assistant, Second Class, of Walter Campbell Smith, who joined the Department on 1 December 1910, the day after his 23rd birthday.

Mention has been made above (p. 54) of help given to Spencer in the measurement of crystals and the determination of refractive indices of valentinite by Herbert Smith, and also of his three-circle goniometer. This was George Frederick Herbert Smith, who had joined the Department soon after the departure of Miers to the Oxford professorship. He was born in 1872 and was less than two years Spencer's junior. His father was headmaster of a boys' school at Five Ways, Birmingham, and later of Doncaster School. He himself was at school at Winchester and went from there, with a scholarship, to New College, Oxford where he took first class honours in Mathematics (1895) and Natural Sciences (Physics) in 1896. Before taking up his appointment at the Museum he was 'persuaded', like Spencer before him, to spend a semester studying mineralogy and crystallography under Groth at Munich, again at his own expense, and with no salary from the Museum. In these days of student grants and post-graduate studentships, this voluntary study abroad at the sacrifice of six months' salary, not to mention postponing the commencement of their Civil Service, seems remarkable.

Herbert Smith's mathematical training was a great help to him in his crystallography, and his knowledge of physics and particularly of optics enabled him to devise improvements in goniometers and to undertake difficult determinations of high value refractive indices. Herbert Smith actually joined the Department in April 1897. He started work on a section of the Crystallographic Catalogue and very early in the course of this work he came across two specimens of atacamite, $4[Cu_2Cl(OH_3)]$, from Sierra Gorda, Chile, bearing very much better crystals than those measured by earlier crystallographers. These he made the subject of his first paper to the Mineralogical Society, read on 1 February 1898 (Herbert Smith, 1898). Using the best-developed faces he determined the axial ratios; studied the etch-figures, confirming thereby the holohedral orthorhombic symmetry of the mineral; determined the refractive indices by the method of minimum deviation on three prisms formed by three pairs of natural faces of the crystals; and showed how to calculate the three principal refractive indices, α, β, and γ, from the measurements obtained (Herbert Smith, 1906*a*). For this work he used a large Fuess goniometer reading to 10 seconds of arc, and for the optic axial angle a Miers microscope-stage goniometer (see p. 51). Several years later Herbert Smith described paratacamite, a new mineral from Sierra Gorda, shown by Prior to have the same empirical formula as atacamite but definitely distinguished from it by its crystal symmetry. The symmetry is pseudo-rhombohedral and the crystals, some of which show a prismatic habit, are invariably twinned. On some specimens the crystals resemble cubes but are actually twinned rhombohedra (Herbert Smith & Prior, 1906). That the two minerals atacamite and paratacamite are distinct was confirmed by Bannister *et al.* (1950), as a result of an X-ray study of these minerals in the collection.

In his second published paper Herbert Smith described several minerals found in the lead slags from the ancient mines at Laurium in Greece. These were laurionite, phosgenite, fiedlerite and a new mineral, paralaurionite. Crystals of each species were measured, forms identified, and axial ratios calculated. Refractive indices were determined using prisms formed by natural faces. Paralaurionite forms monoclinic crystals, tabular parallel to {100}, and almost always twinned, by reason of which it gives a characteristic optic figure in monochromatic light. In measuring these crystals Herbert Smith used a vertical circle goniometer devised by Stöber (1898); (Herbert Smith & Prior, 1899). About two months after this paper had been published there appeared a posthumous paper by Professor Arzruni in which he described by the name rafaëlite a new mineral, an oxychloride of lead, from the San Rafael mine, Chile (Arzruni *et al.*, 1899). Herbert Smith found that the measured angles of rafaëlite were identical with his angles for paralaurionite and concluded that the two minerals were identical (Herbert Smith, 1899*b*).

Herbert Smith's three-circle goniometer has been mentioned previously (p. 58). Two-circle goniometers were already well known and one had been constructed and used by Miller as early as 1874. Herbert Smith attached a third circle to the vertical circle of a two-circle goniometer and this carried an adjustable crystal holder of the usual pattern used on goniometers. By this means, without moving the crystal in the holder, any zone can be brought into adjustment and any face in the zone can be brought parallel to the vertical circle and its position in the zone can be determined. The first instrument was described in April 1899, an improved form was announced in the following year, and the completed instrument was fully described in 1902 (Herbert Smith, 1899*a*, 1901, 1904*a*).

Other instruments preserved in the Department and designed by Herbert Smith include an improved form of hand-held refractometer referred to later (p. 60); a student's goniometer on the Wollaston pattern (Herbert Smith, 1919*b*); and a camera lucida attachment for the horizontal-circle goniometers (Herbert Smith, 1910).

The camera lucida attached to the telescope of the goniometer can be used either for drawing accurate projections of the 'light-figures' obtainable by reflections from imperfectly developed faces or, with the addition of a small lens in front of the eyepiece, for making drawings of the smallest crystals while still positioned for measurement on the crystal holder.

Herbert Smith also designed a protractor for drawing great circles of large radii for stereographic projections on a 10 cm primitive circle. For ruling such curves he used a multiple spring composed of a series of clock springs of suitable length to represent a single spring of variable thickness which is required if circular curves are to be obtained. It is set by a 'pushing piece'

actuated by a screw with a scale giving the inclination of the great circle to be drawn (Herbert Smith, 1913*b*).

Several diagrams were prepared to assist in crystal calculation, including a 'moriogram' for 'rapidly determining the angles between a face of symmetry and all other faces with rational indices which lie with it in some particular zone, when two of the angles are known . . .'. This diagram could be used with accuracy for zones in which the principal poles included a right angle (Herbert Smith, 1904*b*). In a later paper Herbert Smith discussed two methods of obtaining the angles and indices in zones of crystals with triclinic symmetry also. One method was a deduction from the properties of the gnomonic projection, the second an extension of the moriogram (Herbert Smith, 1913*a*). He also published two papers on the use of the gnomonic projection in the drawing and calculation of crystals (Herbert Smith, 1903*b*, 1919*a*; Miers, 1887).

Herbert Smith was actively interested in theories of crystal structure and in 1901 assisted William Barlow and Miers in drawing up their report to the British Association on the development of geometrical theories of crystal structure, 1666–1901 (Barlow *et al.*, 1901; Herbert Smith, 1902). This report was being prepared just at the time that Herbert Smith was grappling with the problem of the crystallography of calaverite (see p. 61).

Soon after his appointment to the Museum Herbert Smith became interested in gemstones and the methods used by jewellers to identify them. He designed an improved form of total refractometer, which could be used in the hand for measuring the refractive indices of cut and polished gemstones. An instrument based on similar principles had been designed by E. Bertrand in 1885 and widely used. The chief improvement in Herbert Smith's instrument lay in the introduction of a compensating lens which enabled the shadow edges on the scale to be sharply defined and capable of being focused. The first form of this refractometer was described in 1904 and the much improved model in 1907 (Herbert Smith, 1905, 1907*b*). The scale on the new model gave refractive indices to two places of decimals and the readable range of the refractive indices was increased to 1.770 (0.02 higher than before), enabling it to be used for corundum, which is very important. Observations with this model are made easier by the insertion of a totally-reflecting prism between the two lenses of the eyepiece.

For crystals and gemstones with refractive indices too high for determination on a total reflectometer Herbert Smith published a short paper 'On the method of minimum deviation for the determination of refractive indices', together with a refractive index diagram which in effect solves the well-known formula in terms of the prism angle and the angle of minimum deviation (Herbert Smith, 1906*b*). In a short paper read to the Mineralogical Society in 1907 he described the manufacture of synthetic corundum by the Verneuil process. By goniometric measurements he showed that the lines intersecting at 60° at the broad end of the boules are formed by minute faces of the fundamental rhombohedron of corundum. In the same paper it was announced that a dark blue boule alleged to be synthetic sapphire was in fact a synthetic spinel. This boule had been submitted to Herbert Smith by Mr Edward Hopkins of Hatton Garden, who had noticed that it was not dichroic (Herbert Smith, 1908).

With Mr Hopkins, Herbert Smith took a very active part in the movement initiated by the National Association of Goldsmiths which, about 1912, instituted courses in gemmology for jewellers and issued diplomas to candidates successful in the examinations. Herbert Smith was one of the examiners for these diplomas for many years. The movement resulted in 1931 in the foundation of the Gemmological Association of Great Britain; Herbert Smith was President of the Association from 1942 until his death in 1953. He published a book *Gem stones and their distinctive characters* in 1912. It ran to its fifth edition by 1926 and now, revised and enlarged by Professor F. Coles Phillips and with the shorter title *Gemstones*, is in its 14th edition. He published numerous short papers on gemstones and the methods of identifying them, contributing, for instance, monthly articles to the *Jeweller and Metalworker* from 1925 to 1927.

Herbert Smith wrote several collaborative papers on minerals, the first being an account with Prior on red silver minerals from the Binnenthal, Switzerland (Herbert Smith & Prior, 1907). This dealt with very small crystals of a scarlet or vermilion colour, collected by R. H. Solly from the dolomite of the Lengenbach quarry. Solly had described crystals of several new minerals from this quarry (1903*a*,*b*; 1905), since when he had obtained more material, including some

better crystals, and it was this material he now submitted to Herbert Smith. From these crystals Prior picked out just sufficient for quantitative analyses. All three proved to be sulpharsenites of lead and were named by Solly. Hutchinsonite was particularly interesting as it contained up to 25% thallium; this orthorhombic species $(Tl,Pb)_2AgAs_5S_{10}$, has since been discovered at another German locality, a lead-zinc mine near Wiesloch in Baden (Ramdohr, 1953; Seeliger, 1953, 1954), and in much larger crystals at Quiruvilca, Peru. Smithite, named for Herbert Smith, is monoclinic, $AgAsS_2$; and trechmannite, rhombohedral, is probably a sulpharsenite of silver. Herbert Smith, using the three-circle goniometer, completely determined the crystallographic characters of all three minerals and, as far as was then possible, made good observations on their optical characters, refractive indices, and specific gravities. This, apart from a short paper describing small crystals of ilmenite from Jacupiranga collected by Dr Hussak and labelled zirkelite (Herbert Smith, 1907*a*), was his only crystallographic paper until 1910 when, on 7 June, he read a paper before the Mineralogical Society on 'Chabazite and associated minerals from County Antrim' (Herbert Smith *et al.*, 1916), which presented the results of a thorough study of the very good specimens collected from quarries on the Antrim coast by F. N. L. Ashcroft and Mr Robert Bell. As a result of his investigations he concluded that the name chabazite should be applied to the whole group (of its varieties) 'and it is convenient to retain the term gmelinite for the apparently hexagonal crystals, and to use the term phacolite in a somewhat widened sense for all the crystals, invariably twinned, of rhombohedral habit, and not merely for those lenticular in shape', as had been the practice. Hey later made gmelinite a distinct species (F. A. Bannister, pers. comm., 1926); that phacolite is a variety of chabazite has been confirmed by X-ray powder photographs (G. F. Claringbull, pers. comm., 1947).

In 1911 Herbert Smith and Prior published two papers on schwartzembergite from the Hohmann collection of South American minerals (Herbert Smith & Prior, 1911*a*); and on fermorite and tilasite from India (Herbert Smith & Prior, 1911*b*). Herbert Smith also investigated the crystal form of nitrogen sulphide (N_4S_4), confirming Artini's determination of its symmetry as monoclinic and obtaining approximate measurements of its refractive indices. In 1913 he contributed crystallographic notes to a paper by G. S. Blake of the Imperial Institute on varieties of zirkelite from Ceylon (Blake & Herbert Smith, 1913).

The crystals of schwartzembergite, from the San Rafael mine, Sierra Gorda, Chile, were shown to be pseudo-tetragonal with very rounded pyramid faces. Measurable reflections were unobtainable and it was on such crystals as these that the device of using a camera lucida to project the 'light-figures' given on reflection of a pin-hole signal was introduced (see p. 59). The optical characters are anomalous, biaxial figures with different orientations in eight sectors of the crystals being observed, whilst the optic axial angles also differ widely in alternate sectors. Prior investigated the chemistry with great care and succeeded in proving that the iodine in this mineral was not present as iodide, as had been supposed, but as iodate, and that schwartzembergite was 'a molecular compound of iodate of lead with an oxychloride having the composition of mendipite, $3(PbCl_2 . 2PbO) . PbI_2O_4$'. He suggested that 'it would seem as if the anomalous morphological and optical characters of the mineral had a direct connection with the abnormal chemical composition', whilst Herbert Smith concluded with the following: 'The curious nature of the morphological characters indicates that in these crystals the intermolecular repulsive forces which prevail in liquids and appear as surface tension are comparable with the intermolecular attractive forces which are responsible for the growth of rigid crystals. Schwartzembergite is therefore one of the links connecting liquid crystals with plane-faced crystals.'

Fermorite, a new mineral discovered by Sir Lewis Fermor in the Sitapar manganese deposit of India, and named after him, was shown by Prior to be, as Fermor suspected, an arsenic analogue of apatite with about 10% SrO, $3[(Ca,Sr)_3(Pb,As)_2O_8 . Ca(OH,F)]$. The other mineral presented to the Museum by Fermor, a pale green arsenate from Kajlidongri, was proved both by Herbert Smith's crystal measurements and by Prior's analysis to be identical with the tilasite from Långban described by H. Sjögren in 1895.

I have left until now any account of the research on which Herbert Smith embarked in November 1900 on the crystallography of the gold telluride, calaverite. The Department had recently acquired a collection of crystals of this mineral from Cripple Creek, Colorado and

among them were some unusual, brilliant yellow crystals which Herbert Smith set out to measure with a view to determining whether they were in fact calaverite. He soon came up against a very remarkable and intractable problem (Herbert Smith & Prior, 1901).

Herbert Smith succeeded in measuring 49 crystals of calaverite, many of which showed a great many forms. One, 3.5 × 0.7 mm in cross section, showed 62 terminal faces representing 42 different forms. The determination of the positions of the faces was greatly facilitated by the use of the recently constructed three-circle goniometer (p. 59).

The morphological development of the crystals led to the conclusion that the crystals were monoclinic, but on this occasion it was found that very many of the faces had to be assigned very complex indices. A further study of the zones in which the numerous faces could be plotted on a gnomonic projection showed that many faces had simple indices when referred to a triclinic lattice (T_1), but there still remained many with very complex indices indeed, e.g: (59.20.5), (49.20.5), (39.20.15). However, all but six could be referred to a second triclinic lattice (T_2) and so receive simple indices. Even the remaining six could be given simple indices if referred to a third, monoclinic lattice (M_3). There are two further lattices to be explained by twinning; so, as Herbert Smith wrote, 'we are, therefore, driven to the remarkable conclusion that five distinct lattices may be traced in calaverite, which are incongruent but not independent. The prism zone is common to all.' He added further: 'in the present state of our knowledge we can do little more than conjecture what may be the actual arrangement of the ultimate parts in any particular mineral although we are agreed that it must belong to one of 230 different classes. The case of calaverite is one of peculiar perplexity.'

Herbert Smith worked on this problem for months; in fact in the end he overworked and had to stop for a time. His final conclusion read: 'the only hypothesis . . . remaining appears to be the existence of a minute skeletal structure of some kind—an infinitesimal framework composed of material with an arrangement according to one lattice intercalated with material with an arrangement according to another lattice.' He noted the extremely brittle character of the crystals and considered that this may indicate that there is a facility for parting which is not in the same direction at every point. This would be explained if the crystals are composed of two individuals so intimately intermixed that the separation is not visible to our perceptions. This is in agreement with the hypothesis stated above, and the existence of skeletal and hollow crystals, and of pits on faces, all suggest breaks in continuity of the homogeneous arrangement.

Half a dozen first class crystallographers worked on the unsolved problem of calaverite during the thirty years following the publication of Herbert Smith's paper. None of them arrived at a conclusion satisfactory to themselves and none of the work was published until 1931 when Victor Goldschmidt, Charles Palache, and M. A. Peacock published 'Über Calaverit' (Goldschmidt *et al.*, 1931) summarized in 'Calaverite and the Law of Complication' (Peacock, 1932). These authors had repeated the plotting of 92 forms on a gnomonic projection as Herbert Smith had done, and arrived at similar results, namely, the need to refer the forms to one or other of five different sets of triclinic axes to obtain simple indices. Goldschmidt's Law of Complication is explained in Peacock's paper.

A problem similar to but less baffling than that of calaverite was presented by the crystallography of sartorite, one of the lead sulpharsenides from the Binnenthal quarry of which R. H. Solly, among others, had made a collection before the quarry closed in 1909. Solly had described some of these minerals at various times since 1900 and had exhibited his specimens of sartorite at a meeting of the Mineralogical Society where he read a paper in June 1914.

Some of his crystals showed very small pyramidal planes, uncommon in sartorite, the positions of which could not be determined satisfactorily on a single-circle goniometer and Solly had asked Herbert Smith to measure the crystals on his three-circle goniometer. This he agreed to do, but two months after the meeting at which the first part of their joint paper on sartorite was read the First World War broke out and it was not until 1916 that Herbert Smith had an opportunity to start work on the measurements. The results were given in a paper read to the Mineralogical Society in June 1917 and published in May 1919 (Herbert Smith & Solly, 1919). He also found among these specimens a single crystal of a mineral different from sartorite, and which he was

able to measure; there was insufficient to analyse and so it remained unnamed (Herbert Smith, 1920).

The crystals measured were described in great detail. The positions of all the faces were plotted on a gnomonic projection and this showed that, as in calaverite, there are five different networks to which the faces are referable, corresponding to three lattices, I, II, and III, and two more related to two of these three by twinning. Lattice I is monoclinic, II and III are triclinic. Only one crystal had many faces referable to lattice III, and for three of the measured crystals all their faces could be referred to lattices I and II. The three lattices in sartorite were found to be positionally related in such a way that each can be transformed into the adjoining lattice by a shear which, in five different crystals, is 'constant in amount but variable in direction'.

Except for his account of crystals of semseyite found by Sir Arthur Russell at Glendinning in Dumfriesshire (Herbert Smith & Prior, 1919) the work on sartorite was Herbert Smith's last contribution to geometrical crystallography. By the time the War was over he had become very much involved in administrative duties, largely outside the Department. During the War he was very active in the General Reserve—the GR's—to which the older members of the Museum staff contributed a small detachment. Also he was being asked to do more and more in the Museum Office during the absence of the Secretary, Mr C. E. Fagan, who was ill. Eventually, after Mr Fagan's death, Herbert Smith was appointed to succeed him in 1921. Although he returned to the Department as Keeper for the last two years of his service (1935–1937) and made several improvements in the exhibition gallery, he never resumed his researches in mineralogy.

In 1911 the Department was literally smothered by the transfer to it of the collection of foreign rocks and minerals from the hundred years old Geological Society's museum. Campbell Smith was assigned the task of cataloguing these collections and arranging their incorporation into the Rock Collection. Campbell Smith, appointed in 1910 (see p. 58), came from Solihull School and Corpus Christi College, Cambridge, where he had read Crystallography and Mineralogy under Lewis and Hutchinson, and Geology and Petrology under Marr and Harker. Being an enthusiastic mineralogist, it was as such that he hoped to be employed, and he did begin work on some of the silicates in the mineral collection as his part in the work on the 'Crystallographic Catalogue'. He also worked in the chemical laboratory under Prior but, because Prior was now fully occupied with meteorites and departmental administration, it was clear that a petrologist was needed and it was a petrologist that Campbell Smith became.

In the circumstances it is perhaps not surprising that Campbell Smith published nothing of a mineralogical nature before the War except his account of the mineral collection of Thomas Pennant (1726–1798) which had just been presented to the Museum by the Earl of Denbigh (Campbell Smith, 1913). The collection was arranged on the lines of Woodward's classification (1729) and came to the Department in its two original cabinets, accompanied by a two-volume catalogue in Pennant's own hand.

On the return in 1913 of the members of Captain R. F. Scott's *Terra Nova* Antarctic Expedition (Campbell Smith, 1928*b*; Campbell Smith & Game, 1954) it was arranged that the Department should co-operate in the working up of the collections of rocks made by the geologists, and this work also fell to Campbell Smith. Then in 1914 came the First World War, and Campbell Smith enlisted for service with the Artists' Rifles.

After the War he spent a week or so with S. J. Shand at Geneva studying under Marcel Gysin the Fedorov method for determining the optical orientation of feldspars using the three-axis Fedorov microscope stage. Returning from this visit he put the method to use and published a paper on the optical orientation of labradorite from St John's Point, Co. Down, Northern Ireland, using material collected many years before with Professor A. Hutchinson (Hutchinson & Campbell Smith, 1912; Campbell Smith, 1928*a*). Campbell Smith's only other mineralogical publication at this time was a description, with chemical analyses by G. T. Prior, of a compact chlorite from Bernstein in Austria then being marketed in London as 'Styrian jade' (Campbell Smith & Prior, 1924), but he devised, with H. H. Thomas, apparatus to enable facets to be ground at any required angle on crystal plates or prisms (Thomas & Campbell Smith, 1914).

The vacancy caused by Herbert Smith's transfer to the Museum Office was filled by the appointment in June 1922 of Edgar Donald Mountain who, as a scholar of Corpus Christi

College, Cambridge, had taken a First in both parts of the Tripos, and had been awarded the Wiltshire Prize for Mineralogy. Previously he had been at Westminster City School and a scholar at Sutton Valence.

Mountain continued work on the Mineral Collection where Campbell Smith left off, and he also worked in the chemical laboratory, contributing analyses to several of Spencer's later papers, notably those on the lead-copper minerals from the Mendip mines (Spencer & Mountain, 1923) and on two new minerals, schultenite and aramayoite (Spencer & Mountain, 1926*a*,*b*). In 1924 he described the crystallography of calcite crystals from Holywell, Flintshire, collected on a visit to Pennant's country with Campbell Smith during the British Association Meeting at Liverpool in 1923 (Mountain, 1924).

A more important paper involving crystallography, optical data, and chemical analyses was Mountain's account of crystals of 'anorthoclase' from Mount Erebus collected by Frank Debenham on Scott's *Terra Nova* Expedition of 1910. In the same paper he described the somewhat similar crystals from Mount Kenya presented to the Museum in 1900 by J. W. Gregory; discussing the nomenclature of these feldspars he concluded that the Mount Erebus crystals should properly be called potash-oligoclase (Mountain, 1925).

His other mineralogical paper published from the Mineral Department described two fine crystals of smithsonite from Broken Hill, Zimbabwe, acquired in 1921 and 1923. These were much better crystals than those available to Spencer in 1908, which were very small, forming later growths on calamine (i.e; hemimorphite) (Spencer, 1908). The new crystals were simple, clear, colourless rhombohedra, up to 7 mm along the edges. Mountain described the crystal form and measured the refractive indices for five lines of the spectrum, using for this purpose the Tutton monochromatic illuminator. He also made two complete quantitative analyses (Mountain, 1926).

This last paper was read to the Mineralogical Society in March. Unfortunately in that spring Mountain was seriously ill with pneumonia and was advised to live if possible in a warmer climate. Most opportunely a vacancy occurred for a lecturer in mineralogy in the Department of Geology at Rhodes University College, Grahamstown, South Africa: Mountain was appointed to the post and resigned from the Museum in December 1926. After Professor E. H. L. Schwarz's early death in 1928 Mountain was selected as his successor and remained Professor of Geology there until his retirement in 1969.

Spencer continued to be active in the post-war period and papers dating from this time concerned the pleochroism of adamite from Chañarcillo (Spencer, 1914), read to the Mineralogical Society back in 1903; a butterfly twin of gypsum from Girgenti, Sicily (Spencer, 1916*b*); turite (= turgite) and some other iron ores from Nova Scotia, based on a collection presented by Dr Henry S. Poole, some time Inspector of Mines, Nova Scotia (Spencer, 1919); new crystal forms in pyrite, calcite, and epidote, with some brief remarks on the decomposition of pyrite specimens in collections (Spencer, 1920*a*); and fibrolite (= sillimanite) as a gem-stone from Ceylon and Burma, describing in particular specimens from the ruby mines of Mogok presented to the Museum by Mr A. H. Morgan. The crystals being clear and transparent, the opportunity was taken to determine the optical constants, refractive indices, and dispersion, using a single plate with prisms polished on two edges. Some crystals originally brought from Ceylon by S. T. Trelawny as far back as 1812 but presented to the Museum in 1920 by Lt Col. C. F. Catt provided one on which good faces were developed, enabling Spencer to determine the crystal forms and the parameters (Spencer, 1920*b*).

After the War was over and the Department again had its full complement of staff, Spencer spent some of his annual leave in the spring of 1923 on a visit to Somerset to collect from the old lead mine dumps of the Mendips. He had collected there in 1898 and read a paper to the British Association at Bristol on leadhillite from the ancient lead slags. In 1923 he collected specimens of several little-known minerals and discovered two new species, chloroxiphite and diabolëite. Quantitative analyses of the new minerals and of mendipite, crednerite, and hydrocerussite were made by Mountain (Spencer & Mountain, 1923).

Early in 1924 Spencer published a paper on euclase and platinum from diamond washings in British Guiana in which he described remarkable sheaf-like groupings and lenticular forms of

euclase crystals. These were found in concentrates derived from a conglomerate in the Kaietur Gorge of the Potaro River. Spencer also identified as platinum some minute, metallic-looking particles found in the concentrates by Mr J. C. Menzies (Spencer, 1924*a*). This was the first published record of platinum in British Guiana, and was doubted by some, but Spencer confirmed his identification in a second paper announcing the discovery at the same locality of grains believed to be allopalladium (Spencer, 1924*b*). However, the allopalladium proved not to be pure palladium but a distinct compound of palladium and mercury, PdHg. Larger grains of the mineral had been investigated by Sir John Harrison in Georgetown, where he was Director of the Department of Science and Agriculture and where he had been Public Analyst for many years before. He had definitely identified mercury as a constituent of these grains and had obtained good estimates of their quantitative composition. Unfortunately Harrison died early in 1926 before a full account of the work was published; Spencer edited all his notes and published an account of the new mineral, which was named potarite (Spencer, 1928*a*).

Later in 1924 Spencer attended the British Association Meeting in Toronto and visited many museums, mines, and mineral collections both in Canada and the U.S.A. It was on this trip that he saw the fluorescence of willemite being used for detecting the mineral on the washing tables at Franklin Furnace. This led to his setting up a fluorescence exhibit near the entrance to the mineral gallery, which was referred to in his paper on the South African occurrences of willemite (Spencer, 1927*e*) and described in the first volume of the *Natural History Magazine* (Spencer, 1928*b*). Spencer's other papers in 1924 and 1926 were on an inclusion of magnetite in diamond from Bultfontein mine (Spencer, 1924*c*); splendid sperrylite crystals from the Tweefontein mine, presented by the Potgietersrust Platinum Mining Company (Spencer, 1926); and two others describing new minerals. One concerned schultenite, occurring as natural crystals of $PbHAsO_4$ on a specimen labelled 'lanarkite' from Tsumeb, South West Africa (Spencer & Mountain, 1926*a*). The specimen of schultenite was analysed by Mountain as was aramayoite, Ag(BiSb)S, from Potosi, Bolivia, a new mineral described by Spencer at this time (Spencer & Mountain, 1926*b*). This new mineral was made the subject of X-ray examination by Kathleen Yardley, working in Sir William Bragg's laboratory at the Royal Institution. It is probably true to say that this was the first example of a new mineral being examined for, or in, the Department of Mineralogy by X-ray examination. Miss Yardley's paper was read to the Mineralogical Society on 2 November 1926, and at the same meeting her paper on baddeleyite (described by Blake and Herbert Smith, 1907) was also communicated to the Society by Sir William Bragg.

Except for his first contribution to the *Natural History Magazine* describing a beautiful, large, 12 525 carat crystal of aquamarine from Minas Gerais (1927*d*), these papers were the last Spencer published during Prior's Keepership; however one may be allowed to record one other paper, although it was the result of work done mainly, and probably, entirely at home. It was entitled 'Specific gravities of minerals: an index of some recent determinations' (Spencer, 1927*c*). In this he collected 2277 determined values of specific gravities of minerals from the mineralogical literature from 1910 to 1927, using the International Table of Constants, part of which Spencer had for years compiled, and *Mineralogical Abstracts* (1915–1927). These values were listed (*a*) in a mineral index in order of increasing value of specific gravity from 1.03 to 19.0 (18 pages), and (*b*) alphabetically, under minerals, giving minimum and maximum recorded values (4½ pages). It is a good example of the laborious compilations of which Spencer produced many other examples in the course of his work and for which many mineralogists have since been grateful.

The year 1926 had been a busy time with the celebrations of the Jubilee of the Mineralogical Society bringing many foreign mineralogists to visit the Department.

Mountain's place was filled in July 1927 by the appointment of Frederick Allan Bannister, a scholar of the Whitgift School, Croydon, and a Goldsmiths' Scholar at Clare College, Cambridge. He was a physicist and after leaving Cambridge had worked for some time in the Western Electric Company's laboratory at Southgate. Very soon after he joined the mineral Department he was launched on a part-time course in X-ray analysis methods in Sir William Bragg's laboratory at the Royal Institution and, in 1928, he set up a 'home-made' X-ray tube in a partitioned-off space in the room formerly occupied by Spencer.

Another notable addition to the staff in 1927 was Miss Jessie M. Sweet, who came as a temporary assistant but was later established and became a Senior Experimental Officer. She helped Spencer with the registration and the slip catalogue of the mineral collection (see p. 48). After the Second World War, during which a large part of the collection was sent out of London and the gallery suffered damage after a fire-bomb attack, she re-arranged the whole collection, an enormous task which occupied eight years. For her devoted service she was awarded the M.B.E. in 1961, just before her retirement.

At the end of 1927, actually on 16 December, his 65th birthday, Prior retired as Keeper and Spencer succeeded him. Dr Max Hutchinson Hey, a mathematician, chemist, and crystallographer came in due course to fill Spencer's place. I hope Spencer's work as Keeper, and the research work of Bannister, Hey and Claringbull, and of later members of the staff of the Department, will be recorded some day by one of my successors. After all, the seventy years about which I have written ended fifty years ago.

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